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ATSB TRANSPORT SAFETY REPORT

Aviation Occurrence Investigation AO-2010-029

Final

Ground strike, N-128UA Sydney Aerodrome, New South Wales 7 May 2010

Abstract

This report was originally released on 1 April 2011; however, it was subsequently discovered that not all of the directly involved party responses had been considered before the report was approved for release. Those comments have now been considered and this version amends the previously released final report.

On 7 May, 2010, at about 1458 Eastern Standard Time (EST), a Boeing 747-422 aircraft, registered N128UA was being operated on a regular public transport flight from Sydney, Australia to San Francisco, USA. Shortly after conducting a reduced-thrust takeoff, the crew was advised by Sydney Air Traffic Control that the aircraft had sustained a ground strike. After completing the appropriate checks and dumping fuel, the crew returned the aircraft to Sydney and landed. A subsequent inspection revealed scrape damage to the aircraft's lower rear fuselage consistent with contact with the runway surface.

Analysis of recorded flight data by the aircraft manufacturer indicated that the aircraft was subject to a wind gust during rotation. That, combined with a high instantaneous pitch rate around the time of lift-off and a reduction in lift due to spoiler deployment, reduced the tail to runway clearance. Another contributing factor was the reduced-thrust takeoff, which increased the aircraft's exposure to wind variations during rotation. The manufacturer also noted that, had the crew applied a smaller left control wheel input at an earlier stage of the takeoff, it was possible that the spoilers would not have deployed, resulting in a small increase in tail clearance.

Although the investigation did not identify any organisational or systemic issues that might adversely affect the future safety of aviation operations, following the occurrence, the aircraft operator revised its flight manual for the 747-422.

FACTUAL INFORMATION

On 7 May 2010, at about 1458 Eastern Standard Time[1], a Boeing 747-422 aircraft, registered N128UA, was being operated on a regular public transport flight from Sydney, Australia to San Francisco, USA. There were four flight crew, 13 cabin crew, and 229 passengers on board.

The pilot in command (PIC) was the pilot flying. The aircraft was configured for a flap 10, reduced-thrust takeoff[2] on runway 34 left (34L)[3]. The weather was fine with an ambient temperature of 23 °C and the automatic terminal information service reported the surface wind as 300˚ magnetic at 10 kts.

The PIC had operated into Sydney many times. He recalled that, on some occasions in similar wind

1 The 24-hour clock is used in this report to describe the local time of day, Eastern Standard Time (EST), as particular events occurred. Eastern Standard Time was Coordinated Universal Time (UTC) + 10 hours.

2 Reduced thrust takeoffs are a standard procedure for airline operators, designed principally to reduce engine wear.

3 Runway heading was 335˚ magnetic.

conditions, he had experienced variable crosswinds from the direction of the international terminal buildings, which had influenced the aircraft around the time of rotation, in the vicinity of the intersection between runways 34L and 25. The PIC conveyed that information to the other crew members as they were taxiing the aircraft for takeoff. During the pre-take-off checks, the first officer commented that the flight controls felt a bit lighter than normal. The PIC operated the controls and agreed that the control resistance was slightly less than normal. However, he considered that the system was within acceptable limits. All other aspects of the pre-take-off checks were normal.

The crew conducted a rolling start takeoff, using the full runway length. The PIC recalled that, as he rotated the aircraft for liftoff, the aircraft's response to his elevator input was 'slightly more aggressive than he would have liked and was expecting'. After rotating, he directed his attention inside the cockpit and used the flight director[4] to set the aircraft in the appropriate climb attitude. None of the crew members recalled feeling or hearing anything unusual during this phase and there were no aircraft system alerts or other indications.

Just prior to the aircraft reaching 1,000 ft above ground level, Sydney Control Tower advised the crew that a departing aircraft had observed the tail of their aircraft contact the runway surface during the rotation for takeoff. The relief pilot made several calls to the cabin crew seeking information about the takeoff. One flight attendant reported hearing a noise at takeoff that 'sounded like freight shifted', but there were no sounds noted by the other flight attendants.

The crew levelled the aircraft at 8,000 ft above mean sea level (AMSL) and completed the *Tail Strike on Takeoff Irregular Checklist*, which included depressurizing the cabin. After dumping fuel to bring the aircraft to below its maximum landing weight, the aircraft was landed at Sydney.

Damage to the aircraft

A post-flight inspection revealed abrasion damage to the lower rear fuselage, which extended from the stabiliser access door to the tailcone, and compression damage to the tailcone (Figure 1). That resulted in minor damage to the auxiliary power unit bay access doors and lower fuselage frames at the tailcone. There was no damage to the pressure bulkhead structure.

Figure 1: Damage to lower rear fuselage

Aircraft information

The aircraft had completed 40,696 hours operation and 4,881 cycles at the time of the occurrence. There were no maintenance items outstanding.

The operator conducted a series of checks related to the elevator control system. All checks were within limits except for the elevator body cable tension, which was slightly low (0.3 lb or 0.14 kg).

Aircraft weight and balance

The aircraft's gross weight was 828,223 lb (375,682 kg) with a centre of gravity (c.g) of 12.7 percent and a trim setting of 8.9 units. The maximum take-off weight was 875,000 lb (396,893 kg). Following the flight, the c.g was confirmed as having been within limits. A post-flight inspection confirmed that all cargo containers and pallets were in their correct positions and properly secured.

Recorded wind information

The Bureau of Meteorology recorded the average wind speed and direction at Sydney Aerodrome at 1-minute intervals. At 1458, the 1-minute average values recorded included a wind direction 327° true and speed of 9 kts, and a maximum gust of 11 kts.

4 Flight instrument generally similar to an attitude director that gives information on pitch, roll and related parameters.

Recorded flight data

Recorded flight data from the event was forwarded to the aircraft manufacturer for analysis. The manufacturer's report on that data stated:

> Plots of the longitudinal and lateral-directional parameters are attached as Figures 1 and 2 [Appendix A], respectively. In general, airspeed at lift-off, lift loss due to spoilers, and rotation rate are primary factors influencing the amount of tail clearance during a takeoff.
>
> The FDR data show that the airplane was configured for a flaps 10 takeoff with the autothrottle armed (Figure 1). The airplane gross weight and center of gravity (c.g.) were approximately 828000 pounds and 13 percent (from provided weight and balance information), respectively. Maximum takeoff engine pressure ratio (EPR) was approximately 1.51 for the pressure altitude and outside air temperature at the airport at the time. However, the EPR was set to approximately 1.46, indicating a thrust de-rate was used for this takeoff. This is equivalent to an approximate 6 percent reduction in thrust. The recorded stabilizer setting was 0.3 units more nose-down than the recommended stabilizer setting of 9 units based on the provided aircraft weight (828,000 lb.) and center of gravity (13%)[5].
>
> The calculated wind data and fluctuations in computed airspeed and vane angle of attack indicate the airplane was encountering shifts in wind speed and direction during the ground roll. The calculated wind data show that there was an approximate 5-10 knot headwind and an approximate 5-10 knot crosswind from the left around the time of lift-off at time 964.6 seconds (Figure 2). Note – Figure 2 denotes a box around the wind data indicating that it is invalid whilst the airplane is on the ground [see appendix A]. This is because the aerodynamic models do not accurately represent the landing gear loads until the weight is transferred completely to the flying surfaces upon liftoff. However, while the airplane is on the ground, wind trending comments can be made based on the recorded air data. Once the airplane is airborne, comments regarding magnitude and specific direction become valid based on the aerodynamic model of the airplane.

The estimated takeoff rotation speed (VR) for the airport conditions and thrust de-rate was 173 knots. The crew initiated rotation at the appropriate airspeed at approximately time 958.2 seconds (Figure 1). However, computed airspeed stagnated just before and during rotation due to a wind gust. Approximately 2.5 seconds elapsed following the initiation of rotation before the computed airspeed exceeded the targeted VR speed. This stagnation resulted in lift-off airspeed approximately 6 knots below the expected value.

Nominal average rotation (pitch) rate for the 747-400 is 2.5 degrees per second per the 747 Flight Crew Training Manual (FCTM). The average rotation rate for the event flight was approximately 2.2 degrees per second (between initial column input and 10 degrees pitch attitude), which was within the recommended range. However, the calculated rotation rate reached a maximum of 4 degrees per second around lift-off. Despite achieving a nominal average pitch rate throughout the rotation, the maximum instantaneous pitch rate was higher than would be expected at lift-off. Analysis of flight test data shows that, on average, a typical commercial airplane will reach a maximum pitch rate approximately 1 degree per second higher than the recommended average pitch rate. For the 747-400, the maximum instantaneous pitch rate will typically reach approximately 3.5 degrees per second. The additional 0.5 degree per second higher instantaneous pitch rate at lift-off for the event flight contributed to the reduction in tail clearance.

The crew's right rudder inputs during the takeoff are consistent with the presence of a crosswind from the left (Figure 2). Rudder inputs ranged from 0 to 10 degrees to the right during the ground roll and through rotation and lift-off. Just after the start of rotation, at approximately time 959 seconds, bank angle began increasing to the right. It reached a maximum of 1.5 degrees at time 961 seconds and was countered by a wheel input of 15 degrees to the left. This wheel deflection resulted in deployment of the flight spoilers. Although small, this spoiler deployment caused some lift loss leading to a further reduction in tail clearance.

Figure 1 [not included in this report] shows the airplane pitch attitude reached the tail strike contact attitude of 12.5 degrees at approximately time 963.3 seconds as evidenced by a sharp spike in normal load factor. The air/ground discrete data also began transitioning between AIR and GROUND around this time. It finally transitioned to AIR at approximately time 964.6 seconds.

5 B747-400 Flight Planning and Performance Manual (D632U001-RZ010; page 1.2.21)

> The primary factors that contributed to the reduction in tail clearance for this event were the airspeed loss during rotation resulting from a wind gust, a high maximum instantaneous pitch rate around lift-off, and a reduction in lift due to spoiler deployment. Nominal tail clearance for a 747-400 at flaps 10 is 39 inches (see Enclosure 4). The lower lift-off airspeed accounted for a reduction in tail clearance of approximately 24 inches, more than half of the nominal clearance. An additional reduction of 3 inches was caused by the spoiler deployment due to the control wheel input. The amount of tail clearance reduction due to the high instantaneous pitch rate around lift-off has not yet been accurately quantified by Boeing for the 747-400. Past history of tail strikes and studies on other models have shown that high instantaneous pitch rates around lift-off can greatly contribute to reduced tail clearance.
>
> An additional factor in the tail clearance reduction was the use of the lower takeoff thrust. A takeoff with lower than maximum thrust reduces tail clearance slightly by increasing the exposure time to wind gusts.

In response to a series of additional questions, the manufacturer advised the following:

- It appeared that the take-off speeds and engine thrust settings were correct for the aircraft's reduced-thrust configuration.
- The recorded stabiliser setting for takeoff was 0.3 units more nose-down than the recommended stabiliser setting for the aircraft's weight and c.g. However, the manufacturer advised that difference 'would have a negligible effect on the tail strike'.
- With regard to the slightly low elevator body cable tension, the manufacturer advised that the cable tension would have to be 'significantly reduced before the crew would notice any difference'.
- The aircraft's response to the recorded elevator control inputs appeared to have been as expected.

An analysis of the recorded flight data confirmed that the aircraft became airborne after a ground roll of 7,837 ft (2,389 m), or about 150 m south of the intersection of runways 34 and 25 Figure 2).

Figure 2: Google Earth image of Sydney Aerodrome. The position of the tail strike on runway 34L is arrowed

Operator analysis of its B747 departures from Sydney

As part of its investigation into the occurrence, the aircraft operator examined the available flight data for its B747 departures from Sydney, and provided the following advice:

> A review of the available flight data for Company B747 flights departing SYD [Sydney] was accomplished. The intent of the review was to seek any departure profile that had similar characteristics as the incident flight. The sample size was just over 900 flights and was filtered to only capture flights departing on runway 34L with a gross weight of 750,000 pounds.
>
> Analysis of the data comparing the incident flight with the other sampled flights did not show any statistically significant trends or characteristics.
>
> In most cases the incident flight displayed near the average in terms of bank angle, Average EPR at takeoff and EPR as a percent of Max. The incident flight only differed in each of these areas by having a negative tail clearance of approximately negative (-) 0.2 feet when the average was approximately 3.5 feet of tail clearance at takeoff.

> When comparing minimum tail clearance and pitch rate, the incident aircraft was more than one full degree per second faster than the center of the population distribution. The average population had a pitch rate range from 1.5 to 2.9 deg/sec with a tail clearance range from 1.5 to 5.5 feet. The data captured showed the incident flight with a pitch rate of 3.55 deg/sec at a tail clearance of -0.2 feet.
>
> The pitch rate was captured as the maximum 2 seconds before and 2 seconds after the minimum tail clearance was captured. As noted in the Boeing analysis of the flight data, the overall average pitch rate for the incident flight was 2.2 deg/sec; however, the instantaneous pitch rate documented by Boeing was 4.0 deg/sec.

The operator also examined the use of reduced thrust by its crews at Sydney, and advised:

> The Company Flight manual Chapter 4, section 10 Takeoff Performance – General contains the guidance regarding the use of reduced thrust for takeoff.
>
> Analysis of aircraft data for Company B747-422 departures from SYD shows that the SYD to SFO and LAX departures have a derated range from a low of approximately 5.7 and up to 9.0 percent. Reduced thrust was used on approximately 80 percent of SYD to SFO or LAX departures for the incident month of May. The average reduced thrust usage between March 2010 and August 2010 was 71% for SYD to LAX and 62% for SYD to SFO.
>
> Analysis of the Company flight data, as noted above, did not show any adverse reduction in tail clearance during reduced thrust takeoffs.

Takeoff and initial climb procedures

The operator's flight manual for the B747 included the following information:

> **10.40.01** - Normals, Departure Flight Operations
>
> Tail Strike Avoidance
>
> **Warning**: With the main gear on the runway, tail contact occurs at approximately 12.5°.
>
> **Warning:** If a tail strike occurs on rotation, do not pressurize the airplane. Land at the nearest suitable airport.
>
> **10.40.03** - Normals, Departure Flight Operations
>
> [PF] Initial Climb.....Establish
>
> At the start of the takeoff, maintain slight forward pressure on the control column, relaxing this pressure at 80 knots.
>
> At VR, rotate the airplane smoothly and continuously with a rate of 3° per second to establish an initial pitch attitude.
>
> **Note:** Proper rotation results in reaching V2 at 35 feet above the runway.

The operator advised that, notwithstanding the flight manual reference to a rotation rate of 3 degrees per second, company instructors had always been trained to use about 2 degrees per second when teaching the proper method of rotation.

The aircraft manufacturer's *Boeing 747 Flight Crew Training Manual* contained a section titled *Takeoff and Initial Climb*, which included the following statements:

> For optimum takeoff and initial climb performance, initiate a smooth continuous rotation at VR toward 15 degrees pitch attitude.
>
> Rotate smoothly at an average pitch rate of approximately 2.5 degrees/second.

The crew reported that the operator placed high emphasis on tail strike avoidance during training. They also reported that there was no training on what pilots should do if rotation did not 'look' normal.

ANALYSIS

The pilot in command's recollection that the aircraft's response to his elevator input during rotation was 'slightly more aggressive than he would have liked and was expecting' was reflected in the flight data analysis, which showed an instantaneous pitch rate of 0.5 degrees per second greater than typically seen for 747-400 aircraft. That higher instantaneous pitch rate occurred during the latter stages of the rotation manoeuvre and coincided with the effect of a wind gust. That reduced the aircraft's speed and acceleration, effectively extending the rotation period while the pitch angle increased. It is likely that the aircraft would have become safely airborne without any increase in the initial pitch rate, albeit a few seconds later, as the wind gust effect subsided.

The average pitch rate of the aircraft during rotation was within the aircraft manufacturer's recommended range. Also, pilots were taught a rotation pitch rate that was in line with that contained in the aircraft manufacturer's Flight Crew Training Manual. On that basis, the

difference between the pitch rate in the operator's flight manual and that recommended by the manufacturer was not considered to have contributed to the occurrence.

The recorded rudder deflections during the take-off roll were consistent with the crew's use of rudder to counter the crosswinds. With respect to roll control, had the crew applied a smaller left control wheel input at an earlier stage of the takeoff, it is possible that the spoilers would not have deployed. In turn, that would have provided for a small increase in tail clearance.

FINDINGS

From the evidence available, the following findings are made with respect to the tail strike at Sydney Aerodrome, New South Wales on 7 May 2010 involving Boeing 747-422 aircraft, registered N128UA, and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- The aircraft's speed stagnated briefly when it was subject to fluctuating surface wind conditions during rotation for takeoff.
- As the pilot applied right control input to counter crosswind effects, the flight spoilers activated resulting in a small loss of lift.
- The pilot's elevator input increased the instantaneous pitch rate beyond that typically seen for B747-400 aircraft.
- The reduced-thrust takeoff increased the aircraft's exposure to wind gusts during rotation.

SAFETY ACTION

Following the occurrence, the aircraft operator advised that it had taken the following actions:

1. Flight Crew Training and or Guidance regarding the recognition and response to an abnormal rotation rate

[The operator] will continue to train the proper rotation rate of 2-2.5 degrees per second. [The operator] does not see the benefit in attempting to modify the flight training simulator into simulating external conditions or forces on the yoke that are not normal. By continual repetition of normal rotation rates, with normal stick forces, [The operator] is able to produce repeatable performance from our pilots. By using this approach, we teach the rotation and forces required to be "second nature" to our pilots allowing them to recognize any non-normal "feel" and compensate accordingly.

2. UAL Flight Manual Revision

During the course of the internal Company tail strike investigation, it was noted that the rotation rate, documented in the Company Flight Manual, for the Pilot Flying during take off rotation was a pitch rate of 3 degrees per second to establish the initial pitch attitude. This was subsequently revised to 2.5 degrees per second, which is in line with other Company fleet types and matches the rotation rate in the [Aircraft Manufacturer] Flight Crew Training Manual (FTCM). The revision will come out in the January 2011 update.

(Reference [The operator's] 747 Company Flight Manual Normals, Departure Flight Operations 10.40.3)

Additionally, the Flight Training Center reports that they have always trained Company instructors to use about 2 degrees per second when teaching the proper method of rotation. Pursuant to the upcoming revision, the Training Center always emphasizes changes to the FM when they are published.

SOURCES AND SUBMISSIONS

Sources of information

The sources of information during the investigation included the:

- flight crew
- aircraft operator
- aircraft manufacturer
- Bureau of Meteorology
- Google Earth.

Submissions

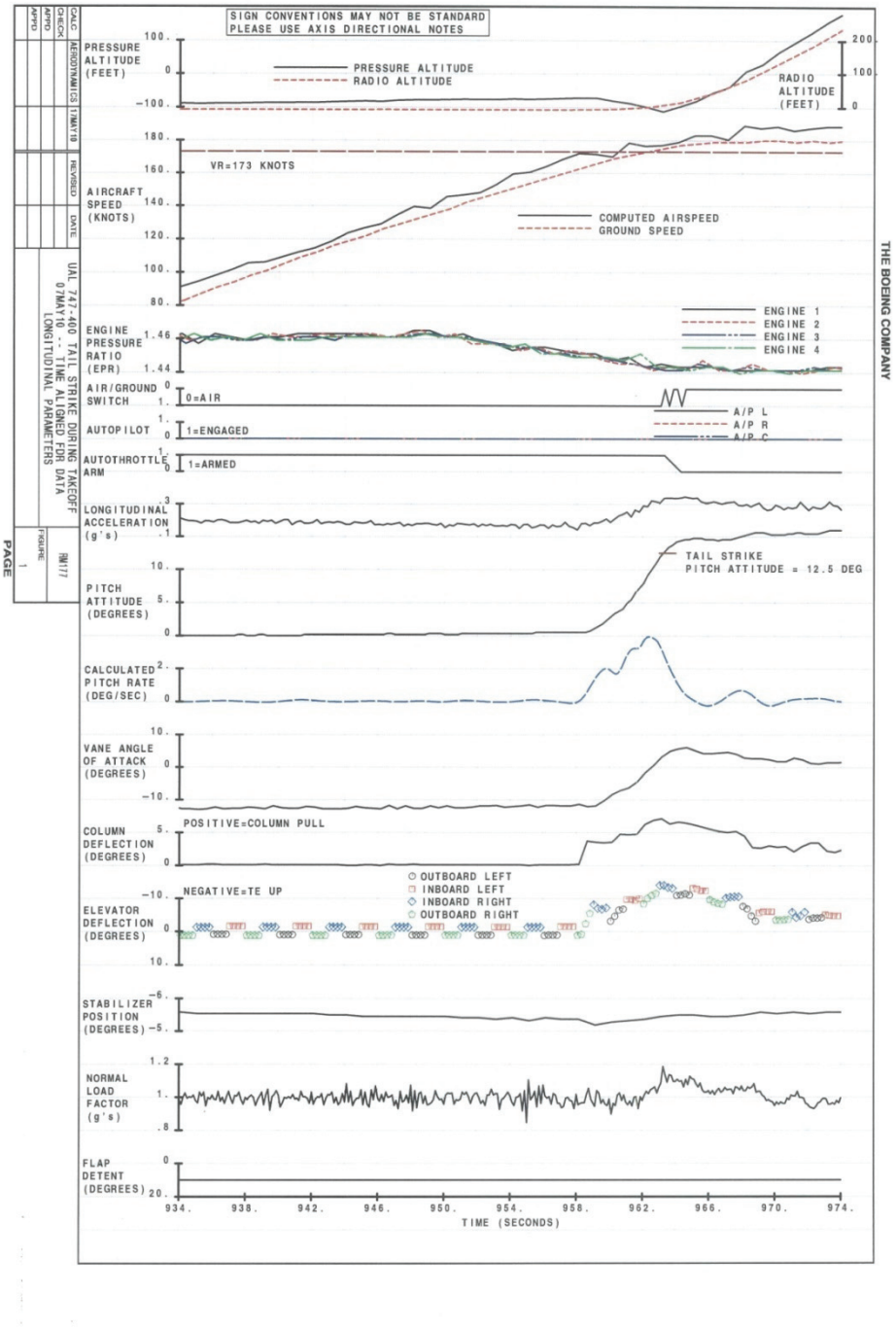
Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003* (the Act), the Australian Transport Safety Bureau (ATSB) may provide a draft report, on a confidential basis, to any person whom the ATSB

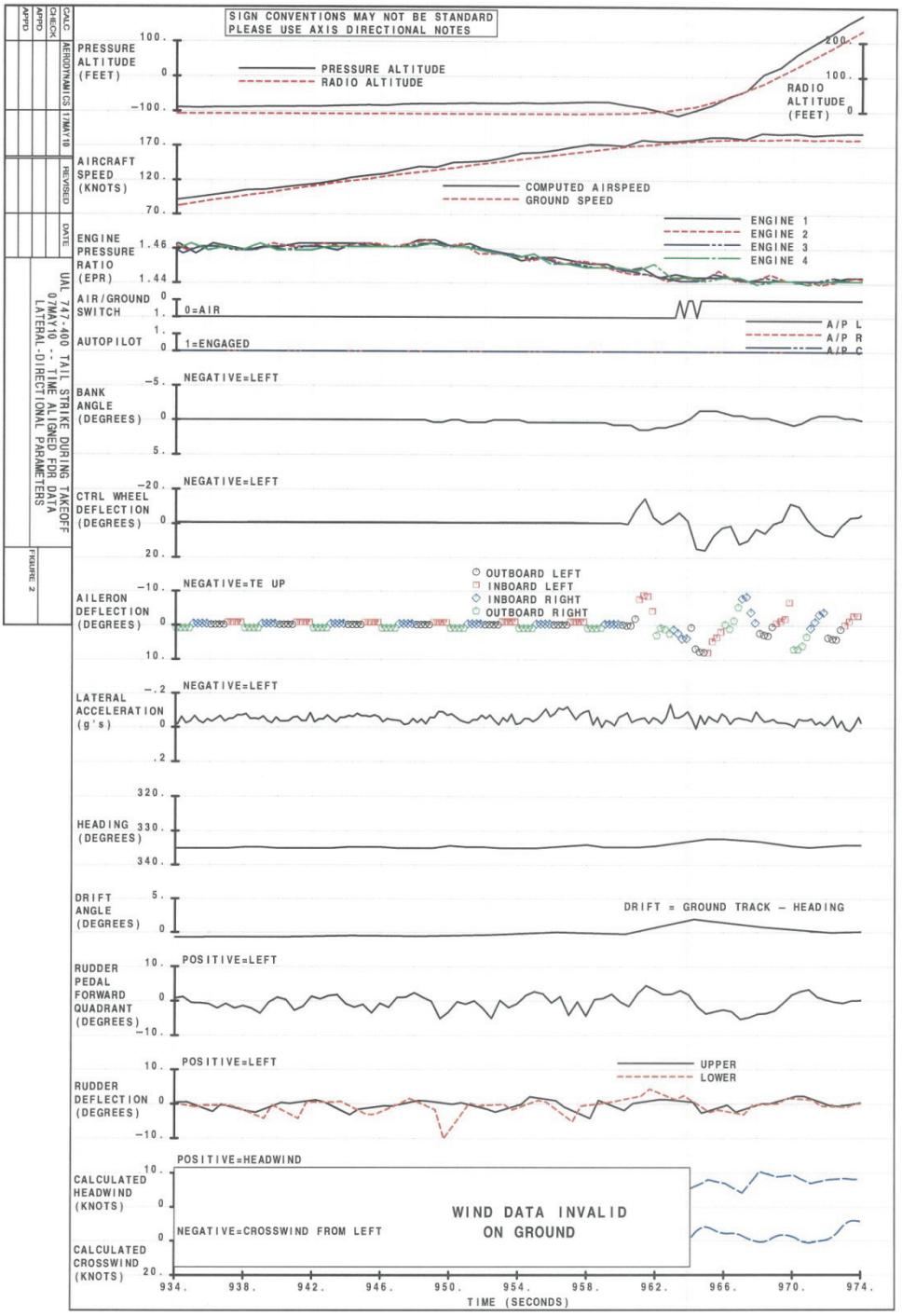
considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A copy of the draft report was provided to the aircraft operator via the United States National Transportation Safety Board (NTSB), the aircraft manufacturer, the flight crew and the Civil Aviation Safety Authority. Submissions were received from the NTSB, the manufacturer, the aircraft operator, and the pilot in command. The submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly

APPENDIX A – AIRCRAFT MANUFACTURER'S ANALYSIS OF FLIGHT DATA

Enclosure 1 to 66-ZB-H200-ASI-18555




SIGN CONVENTIONS MAY NOT BE STANDARD
PLEASE USE AXIS DIRECTIONAL NOTES
PRESSURE ALTITUDE (FEET)
PRESSURE ALTITUDE
RADIO ALTITUDE
RADIO ALTITUDE (FEET)
AIRCRAFT SPEED (KNOTS)
COMPUTED AIRSPEED
GROUND SPEED
ENGINE PRESSURE RATIO (EPR)
ENGINE 1
ENGINE 2
ENGINE 3
ENGINE 4
AIR/GROUND SWITCH
0=AIR
AUTOPILOT
1=ENGAGED
A/P L
A/P R
A/P C
BANK ANGLE (DEGREES)
NEGATIVE=LEFT
CTRL WHEEL DEFLECTION (DEGREES)
AILERON DEFLECTION (DEGREES)
NEGATIVE=TE UP
OUTBOARD LEFT
INBOARD LEFT
INBOARD RIGHT
OUTBOARD RIGHT
LATERAL ACCELERATION (g's)
HEADING (DEGREES)
DRIFT ANGLE (DEGREES)
DRIFT = GROUND TRACK – HEADING
RUDDER PEDAL FORWARD QUADRANT (DEGREES)
POSITIVE=LEFT
RUDDER DEFLECTION (DEGREES)
UPPER
LOWER
POSITIVE=HEADWIND
CALCULATED HEADWIND (KNOTS)
NEGATIVE=CROSSWIND FROM LEFT
CALCULATED CROSSWIND (KNOTS)
WIND DATA INVALID ON GROUND
TIME (SECONDS)
UAL 747-400 TAIL STRIKE DURING TAKEOFF
07MAY10 -- TIME ALIGNED FDR DATA
LATERAL-DIRECTIONAL PARAMETERS
FIGURE 2
THE BOEING COMPANY